Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 14 (2012) 955 – 963

Energy Procedia

Conference Title

Energy assessment of Paper Machines

Naveen Bhutani[a], Carl-Fredrik Lindberg[b], Kevin Starr[c], Robert Horton[c]

[a]*ABB Corporate Research Center, Bangalore, India*
[b]*ABB AB, Corporate Research, Sweden*
[c]*ABB Process Automation Services, USA*

Abstract

There is a large value in making Pulp and Paper mills more energy efficient. ABB has developed an energy assessment service where opportunities to save energy in the paper machine are identified. The energy assessment is done by quantifying energy flows, benchmarking energy users, data mining and steam sensitivity analysis and by experiments and additional measurements at the paper machine. Energy quantification helped in identifying main energy consumer, benchmarking was useful to assess the gap between operating performance and best performance whereas data mining and steam sensitivity analysis helped in studying the impact of key operating variables on performance of paper machines. After the assessment an action plan was presented to the mill for energy efficiency improvement together with a return on investment.

Keywords: paper machine, steam, energy assessment, benchmarking

1. Introduction

Paper machines consume a large amount of energy and in most cases large savings are possible. An approximate overview of the dryer section of a paper machine is presented in Fig. 1. The energy flows in the paper machine in the form of steam, condensate, air, water streams and paper. The paper is dried when it travels on the steam heated cylinders. The moisture in the paper is ventilated away and heat is recovered from exhaust air by air-air heat exchangers and transferred to the inlet air, which is partly heated further in a steam-air heat exchanger. The air to the machine hall is also heated in air-air exchanger and steam-air exchanger. The condensate from steam heated cylinders is flashed in a condensate tank. Most of the flash steam is recovered by thermo-compressors and recirculated back to steam cylinders whereas the remaining flash steam goes to the condenser. The condenser is water cooled and produces warm water by absorbing heat from flash steam. Some paper machines also use steam box which makes pressing more efficient at the expense of steam consumption.

* Naveen Bhutani. Tel.: +91-96-1110-5902; fax: +91-80-4206-9999.
E-mail address: naveen.bhutani@in.abb.com.

doi:10.1016/j.egypro.2011.12.887

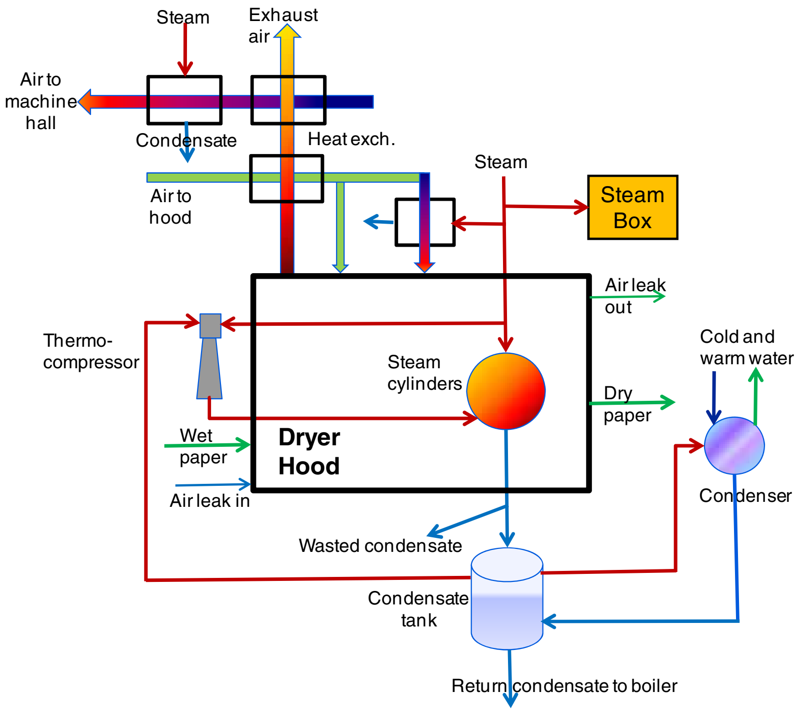

Fig. 1. Schematic of paper dryer section of a paper machine

The challenge is to find where energy is wasted and savings are possible. Measuring and improving energy performance is of course not a new idea, in [1] and [2] different ways are presented. Several other authors e.g. [3-7] have found that the pocket air ventilation, hood balance and dew point have significant influence of paper machine energy efficiency.

Some of the general examples that influence energy efficiency are as follows.

- Type of equipment (design efficiency and condition)
- Lack of equipment (e.g. no heat exchanger, no steam box)
- Plant design (e.g. use/waste of flash steam and condensate, heat recovery system)
- Control strategy (inefficient strategy causes waste of energy, e.g no dew point control.)
- Operation (Manual control, choice of set-points)
- Maintenance (of e.g. heat exchangers, steam traps, valves, sensors, insulation, leaks, tuning control loops, etc.)
- Sensors (calibration, lack of sensors for monitoring and/or control)
- Etc.

To save energy it is important to first identify the saving potential for different actions, relative investments required, and then accordingly prioritize the actions. It is also useful to quantify the energy flows inside the paper machine, both to find the main energy consumers, where probably the largest savings can be found and to make the mill more aware of their energy consumption distribution in general.

2. Steam Energy Fingerprint Tool

ABB have recently developed a paper machine steam energy fingerprint (audit) method to

- Quantify energy flows
- Benchmark steam energy efficiency of drying section of paper machine
- Study the influence of key operating variables on steam efficiency of paper machine.
- Suggest to the mill how to improve energy efficiency together with a pay-back calculation.

The presented method is based on measurements and experiments performed to derive performance indices and calculate energy flows. In many cases measurements were missing, therefore temporary measurements or estimations based on other signals were used, and in worst case only specifications on current equipment were compared with state of the art equipment for performance and saving potential estimation. The outcomes from this study were useful in identifying potential opportunities for energy savings as well as improved production in paper machines.

2.1. Energy Quantification

The tracking of energy flows inside the paper machine is useful to identify main energy consumers, largest waste flows and increase understanding of the process. Energy flows are more difficult to calculate due to limited measurements through online sensors. Particularly the steam flow sensors are often rare in the mill. Therefore, as one instance, the steam flows to steam groups were indirectly estimated. The condensate flow from condensate tanks were first determined by measuring the rise time in the condensate tanks by switching off their effluent flow valves. Based on the rise time, gain in condensate height, and the cross section area of tanks, condensate flows from the groups were calculated. Under steady state, the calculated condensate flow was balanced against steam flow to the group. The same method is applicable to other mills where no direct measurements available for steam/condensate for steam groups. The method is time consuming but a few experiments are sufficient to correctly map steam energy flow to steam groups. The steam consumption in steam-air heat exchangers were estimated based on air flow, humidity and temperature measurements. The estimation was based on assumption that heat transfer efficiency of exchangers was 100%. Energy flow to the condenser was known from its dedicated energy flow meter. Steam flow to the steam box and total steam flow to paper dryer section was available from online sensors. Model equations were applied to calculate energy flow of steam, condensate and moist air in the paper machine. Overall steam energy balance between main consumers and the total steam to paper machine was quite accurate. The bar-graph in Fig 2 was obtained, which shows the relative energy consumption (% distribution of steam energy) in the dryer section.

One of the important findings was, more than 10% of the total steam energy was going to the condenser, which indicates that the excess flash steam was lost to condenser due to poor steam control. One contributor to the large steam flow to the condenser was inefficient thermo-compressors. To countercheck this, a thermogram of a thermo-compressor was used. Fig. 3 below shows that the temperature of the mixed steam is only 2.4 degrees lower than on the motive steam pipe. This is an indicator of very little flash steam being recovered in thermo-compressor.

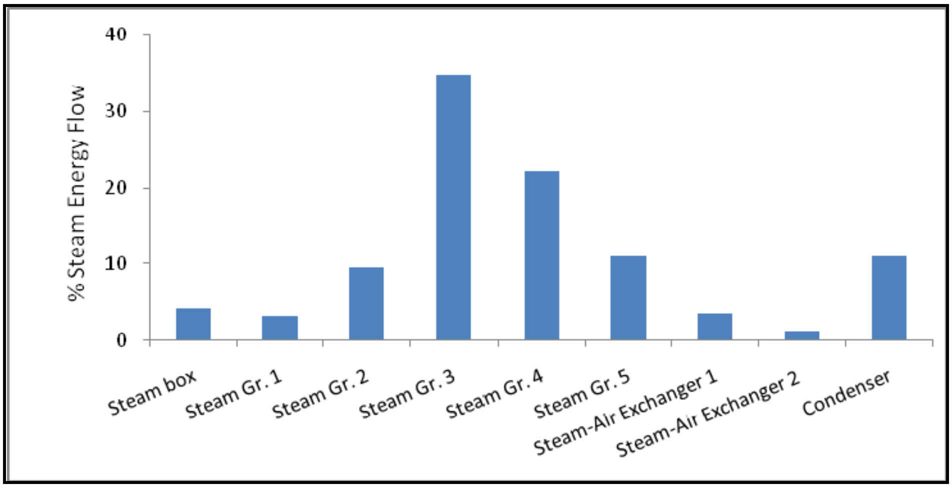

Fig 2 Percentage distribution of steam energy in the dryer section

Normally a thermo-compressor with no insulation is quite rare in paper mill. In such cases thermal imaging is not useful. As an alternative, the impact of thermo-compressor on steam consumption can also be identified by comparing steam consumption under its normal operation and when it is switched off. Therefore, to check if the current thermo-compressor had any influence on total steam consumption or condenser load, it was switched off for some time. No change was observed on the total steam consumption or condenser load during this time. Therefore, it was proved that the energy could potentially be saved by recovering more flash steam in thermo-compressor and reducing the flow to the condenser.

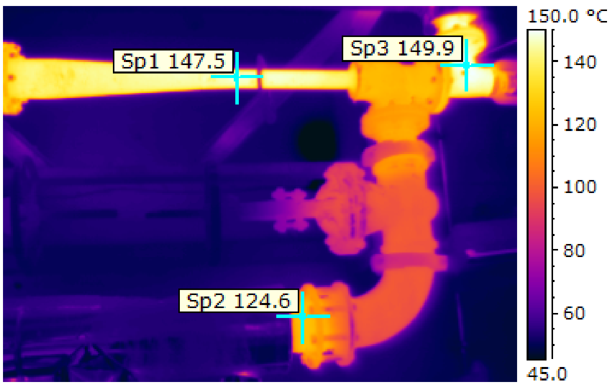

Fig. 3. Thermogram of a thermo-compressor

Less than 5% of the steam was used in the steam air heat exchangers (Fig 2), which means that the saving potential by using an optimal dew point in the hood was smaller than expected. This study was, however, done in the summer. In the winter the steam consumption and saving potential could be larger.

2.2. Energy Benchmarking

Various benchmarks were proposed to determine the energy efficiency of the mill. Below follows some examples:

- Ton steam / ton dry paper
- Tons Steam / tons water evaporated
- Electricity kWh / ton paper
- Condensate return ratio to power house
- Dew point in hood (exhaust air)
- Sheet consistency after press section
- Availability, uptime / total time
- Performance, actual speed / max for that grade
- Quality, good tons / total
- Overall equipment effectiveness (OEE)

Some of these and other performance indices for current performance were compared with their historical best values to identify opportunity for cost/steam savings by operations improvements.

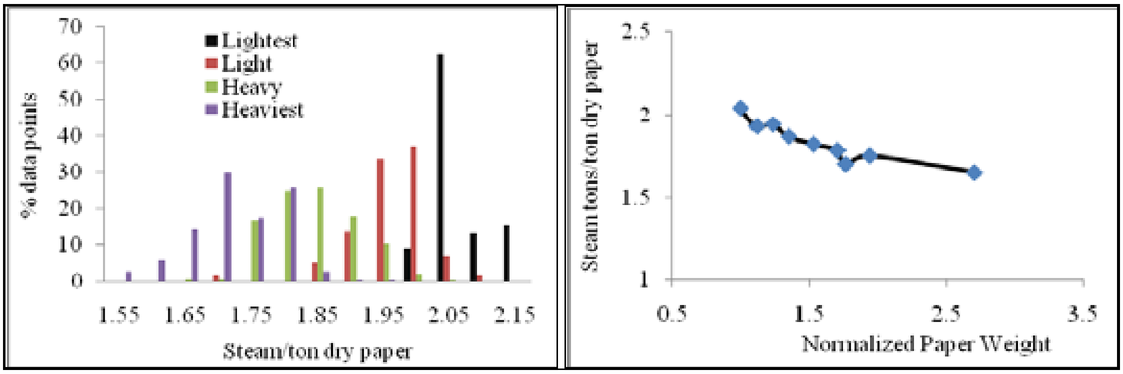

Fig. 4 Effect of paper weight on steam consumption/ton dry paper

The histogram in Fig. 4 (left) presents the steam consumption/ton dry paper for different weights of paper. The steam consumption varies between 1.6 to 2.2 tons steam/ton dry paper for the heaviest to lightest weight paper. In Fig. 4 (right) the paper with heaviest weight has its mean value of tons steam/ton dry paper of 1.7 while the paper with lightest weight has its means value of 2.05. This clearly indicates that the heaviest paper consumes less steam/ton of dry paper. Also, for a given type of paper, there is lot of variation in steam consumption/ton of dry paper. For example, for the heaviest paper, the steam consumption/ton dry paper varies between 1.5 and 1.93. This signifies that, there is a scope to reduce steam consumption by reducing the variations in steam/ton. For example, if 50 % of the production uses 0.1 ton of less steam /ton of dry paper, the steam bill would be reduced by 2.5%.

At this mill the degree of superheat of steam was quite high (>20 °C) at 3 bars and 160 °C. Transmission of wet steam can lead to water hammering by condensate and scale formation in pipes and heat transfer surfaces. On the other hand if the steam is highly superheated, the heat transfer efficiency of equipment goes down.

The benchmarking is useful to identify gaps between standard performance and current operating process performance. By use of simplified models, it is easy to do benchmarking and track energy flow/distribution/efficiency/losses and analyse the influence of key operating variables/metrics on operating performance. As an example, to track energy flow distribution in the paper dryer section, mass and energy balances were applied to the pre-dryer section of a paper machine. The energy flow with steam, condensate, air, wet web and evaporated water were calculated as shown (Fig. 5). Also, the evaporation specific steam consumption i.e. tons steam consumed/ton water evaporated (an important metrics for benchmarking), is calculated as 1.63 for this case. Therefore, the model equations, proved useful not only to track energy flow in the paper dryer section but also calculating a metrics which can be used to set a benchmark and evaluate paper dryer performance with reference to it.

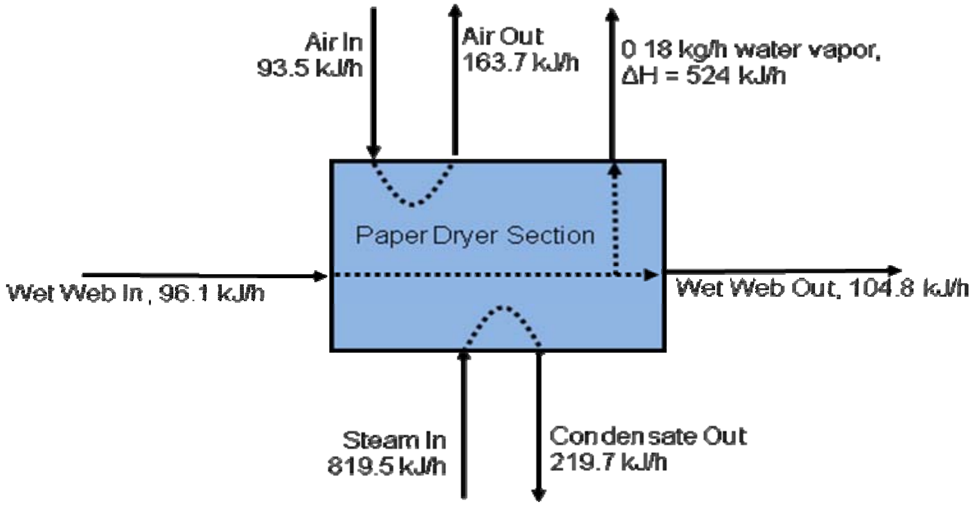

Fig. 5. Energy flow distribution in the pre-dryer section of a paper machine

2.3. Data Mining and Steam Sensitivity Analysis

In a paper machine, many signals are interacting and it is difficult to map the effect of operating variables on process performance if they are not measured directly. For example, the inlet moisture to paper dryer is not measured and it is difficult to obtain it by size press calibration or predict it due to the need for accurate dry end calibration. Therefore, a data mining tool was developed to identify signals (measured variables) which had significant impact on steam efficiency of paper machine and recommend new set points that would save steam. The data was first segregated into different sets based on the weight of paper. The empirical correlations were then developed between various input signals and output (steam efficiency i.e. steam/ton of dry paper) by means of regression. The input signals that had strong influence on output were used for prediction and calculation of steam savings. It was found that the increase in reel speed and reduction of differential pressure of steam drums group could improve steam efficiency (Fig. 6). Better control over these variables will potentially save steam between 2-5%.

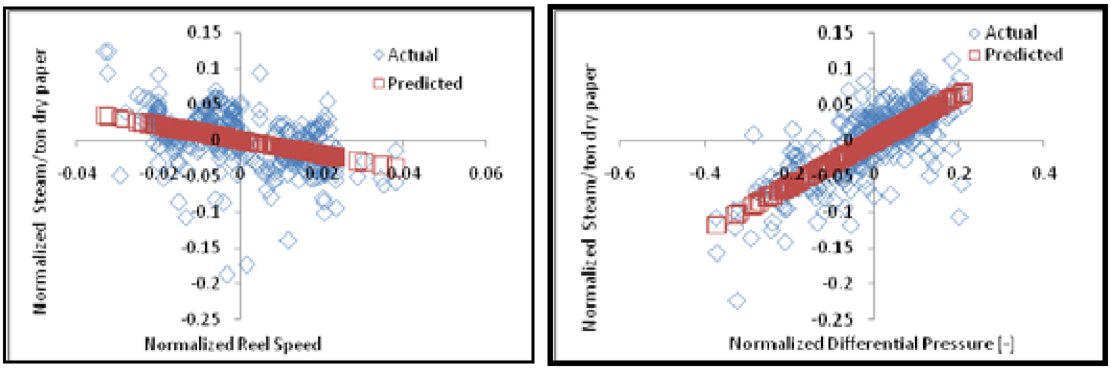

Fig. 6 Effect of key operating variables on steam efficiency

2.4. Experiments and Additional Measurements

The paper machine had very limited online sensors and moreover the control strategy and loop performance cannot be tested without conducting experiments i.e. change the set-points / actuator positions of key operating variable and log energy / steam consumption. Therefore, a few experiments were conducted with steam box by changing (giving ramp input to) its set point pressure and recording its influence on total steam consumption, paper moisture profile and the pressure in steam drums groups. It was found that the steam box could reduce the total steam consumption up to a limit but when the increase in steam flow to steam box got saturated it did not improve dewatering anymore. An approximate savings of 2.5 % in steam savings were identified. Similarly, a test was done where the air flow to and from the hood was reduced by 5% and resulting hood humidity and steam consumption was measured but no identifiable change in humidity or steam consumption was observed. It was concluded that a larger change was required to see the difference, but it was not done to avoid disturbing the system. Since some of the problems related to heat transfer and heat losses due to heat leaks cannot be detected by naked eyes, an investigation with thermal imaging of dryer cylinders, hood, steam traps, and other equipment had been done.

A typical thermogram of dryer cylinders in the end of the paper machine is presented in Fig. 7, where the maximum and minimum temperatures are given along the cyan lines in the image on the left. After investigation, only minor problems were found with steam heated cylinders. For example one of the cylinders was cooler in the end, and another cylinder was dirty which caused stripes in the thermogram of the cylinder (Fig. 7)

The dryer cylinders are very shiny and sometimes it is possible that one gets the temperature of the reflected object than the steam cylinder itself if the thermal camera is not placed/mounted correctly. Also it is difficult to tune the emissivity, the tuning parameter for thermal imaging, which varies with the type of material and its properties for which the temperature is measured. Though, it was difficult to trust the measured absolute values of cylinders surface temperatures completely due to their sensitivity to emissivity factor, the relative values for measured temperatures using same emissivity in all thermograms, proved to be useful. The thermograms were useful to detect temperature gradients along a cylinder and temperature differences between different cylinders that could be used to detect of poorly working cylinders.

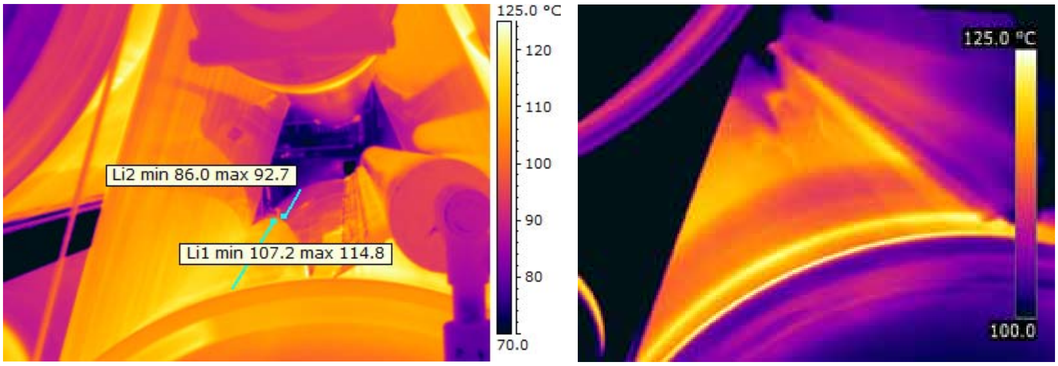

Fig. 7 Thermogram of dryer cylinders

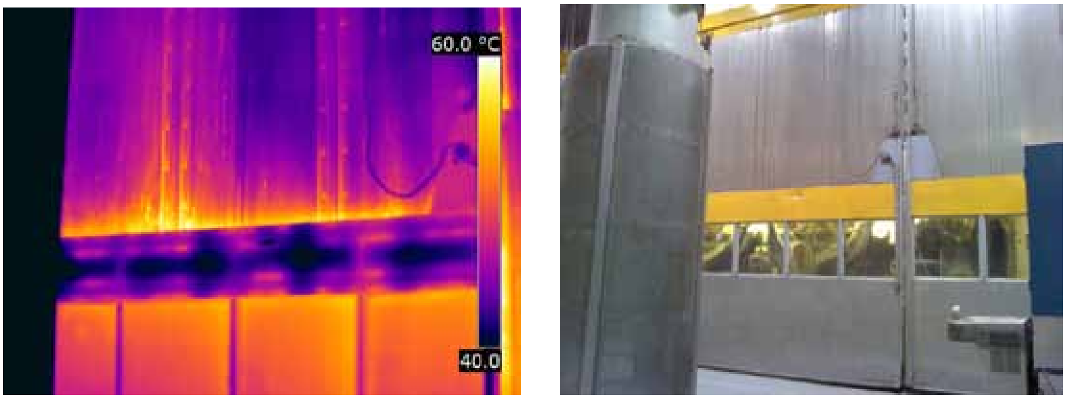

Fig. 8 Thermogram and normal photo of hood.

A thermogram and normal photo of a section of the hood is shown in Fig. 8. It can be seen that the outside surface temperature of hood above the door is higher than surrounding, which signifies the leakage of hot air from the hood. Therefore, the sealing of heat leak would save energy and reduce the humidity in the machine hall. The need for ventilation in the machine hall will also reduce if there is less leakage of moist air from hood to machine hall, signifying steam savings for heating of the machine hall air.

2.5. Conclusions

ABB's recently developed paper machine steam energy fingerprint (audit) solution is suitable for evaluation of steam cycle of the paper machine. By quantifying, benchmarking and data mining, the steam supply, use and inefficiency can be measured. If the loss of energy is beyond specifications, then the poor operating performance can be identified and target solutions can be applied.

In this paper an investigation of the dryer section of a paper machine has been done and the potential steam savings of 10-15% are possible by reducing process variations, optimizing control set points for steam dryers groups, repairing and/or improving operation of thermo-compressors, optimizing steam box pressure, seal leaks of hoods etc.

References

[1] Kuvalekar D. Reducing Specific Steam Consumption through Automation in Steam Systems, *Proceedings of PAPAEREX 2007*, New Delhi, India, December 7-9, 2007.

[2] Reese D. Measuring Paper Machine Energy Performance, *Proceedings of PaperCon '09, St. Louis, USA*, 2009

[3] Ghosh A. K. A Systematic Approach to Optimise Dryer Performance and Energy Savings – Case Studies, *Proceedings of PaperCon '09, St. Louis, USA,2009*.

[4] Ghosh A. K. Optimization of Paper Machine dryer section, *Proceedings of 7th int. conf. on pulp, paper and conversion industry, PAPEREX 2005,* New Delhi, 2005.

[5] Kilponen L. Improvement of Heat Recovery in Existing Paper Machines, *Lic-thesis*, Department of Mechanical Engineering, Espoo, Helsinki University of Technology, 2002.

[6] Lindell K., and Stenström S. Assessment of Different Paper Drying Processes to Reduce the Total Energy Costs From a Mill Perspective”, Drying *2004 – Proceedings of the 14th International Drying Symposium, São Paulo, Brazil, 22-25 August 2004,* p. 1233-1240.

[7] Sivill L. and Ahtila P. Energy efficiency improvement of dryer section heat recovery systems in paper machines – A case study. *Applied Thermal Engineering, 2009;* 29, p. 3663-3668.